

*CHOICE, CHANGING OVER, AND
REINFORCEMENT DELAYS*

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In three experiments, pigeons were used to examine the independent effects of two normally confounded delays to reinforcement associated with changing between concurrently available variable-interval schedules of reinforcement. In Experiments 1 and 2, combinations of changeover-delay durations and fixed-interval travel requirements were arranged in a changeover-key procedure. The delay from a changeover-produced stimulus change to a reinforcer was varied while the delay between the last response on one alternative and a reinforcer on the other (the total obtained delay) was held constant. Changeover rates decreased as a negative power function of the total obtained delay. The delay between a changeover-produced stimulus change had a small and inconsistent effect on changeover rates. In Experiment 3, changeover delays and fixed-interval travel requirements were arranged independently. Changeover rates decreased as a negative power function of the total obtained delay despite variations in the delay from a change in stimulus conditions to a reinforcer. Periods of high-rate responding following a changeover, however, were higher near the end of the delay from a change in stimulus conditions to a reinforcer. The results of these experiments suggest that the effects of changeover delays and travel requirements primarily result from changes in the delay between a response at one alternative and a reinforcer at the other, but the pattern of responding immediately after a changeover depends on the delay from a changeover-produced change in stimulus conditions to a reinforcer.

Key words: choice, concurrent schedules, changeover delay, travel, reinforcement delay, key peck, pigeons

The matching law has described concurrent-schedule performance well (for reviews, see Catania, 1966; Davison & McCarthy, 1988; deVilliers, 1977; Mazur, 1991); however, it is generally agreed that matching is likely an outcome of some more fundamental process (e.g., Baum & Aparicio, 1999; Herrnstein, 1982; Herrnstein & Vaughan, 1980; MacDonall, 1998, 1999; Myerson & Miezin, 1980; Pliskoff, 1971; Shimp, 1966, 1969; Silberberg, Hamilton, Zirias, & Casey, 1978; Vaughan, 1981, 1982; Williams, 1988; cf. Skinner, 1950). Attempts to account for matching vary in terms of level of analysis, but many share a focus on patterns of changing between alternatives (or inversely, the distributions of what have been called dwell times, inter-changeover intervals, stay times, or visit durations). Commenting on a changeover-based

account of matching, Pliskoff (1971) suggested that "The changeover model more easily employs the language of response and consequence common to behavior analysis, and to that extent, it enjoys an advantage over the response distribution and time allocation models" (p. 255). Changeover-based accounts of concurrent-schedule performance have received empirical support (e.g., Pliskoff, 1971; Shull, Spear, & Bryson, 1981; Williams & Bell, 1996; but see Williams & Bell, 1999), but the reinforcement contingencies that control changing over and the means by which such contingencies could produce matching are not well understood.

One robust finding is that changeover rates vary inversely with the delay to reinforcement following a changeover response (e.g., Jones & Davison, 1996; Pliskoff, 1971; Shahan & Lattal, 1998; Shull & Pliskoff, 1967; Shull et al., 1981; Temple, Scown, & Foster, 1995). The effects of the first delay to reinforcement incurred after a changeover have been studied primarily by varying the duration of the changeover delay (COD), which specifies the minimum time from a changeover until the availability of a reinforcer on the changed-to schedule. Changeover delays are standard in concurrent-schedule procedures because in

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their absence rates of changing between the alternatives are high and relative response rates are insensitive to changes in relative reinforcement rates (i.e., severe undermatching results; Catania, 1963, 1966; Catania & Cutts, 1963; deVilliers, 1977; Herrnstein, 1961; Shull & Pliskoff, 1967; Temple et al., 1995; but see Heyman, 1979, and Baum, Schwendiman, & Bell, 1999).

Pliskoff (1971) and Shull et al. (1981) suggested that the COD has such a large impact on matching because the reinforcement rates used to describe choice in the matching law can be converted into a series of delays to reinforcement following a changeover. Shull et al. showed that changing over was frequent when the first delay to reinforcement following a changeover was short, even when changing over considerably decreased overall reinforcement rate. Thus, the results of Shull et al. and experiments examining the effects of COD duration show that reinforcers delivered soon after a changeover disproportionately affect changing over and preference. The fact that the disproportionate effects of these delays to reinforcement are inconsistent with accounts of choice that give equal weight to all reinforcers (e.g., melioration) stresses the importance of understanding these delays in accounting for choice (cf. Herrnstein, 1982, 1991; Herrnstein & Vaughan, 1980; Williams, 1988).

Shahan and Lattal (1998) noted that the effects of the delay to reinforcement following a changeover are complicated by a confounding effect that arises when COD duration is manipulated. The completion of a changeover response immediately changes the stimulus conditions (e.g., the main-key stimulus changes in changeover-key procedures or the subject is in a different location in two-key procedures), and increasing the COD increases the delay from this stimulus change to reinforcer availability. In addition, increasing the COD increases the delay from the last response on one alternative to the possibility of reinforcement on the other. The top panel of Figure 1 shows the confounding effect between these two delays with a diagram of the programming of a COD in a changeover-key procedure. In changeover-key procedures, the COD is timed from a response on the changeover key (COK in Figure 1). This response changes the main-key

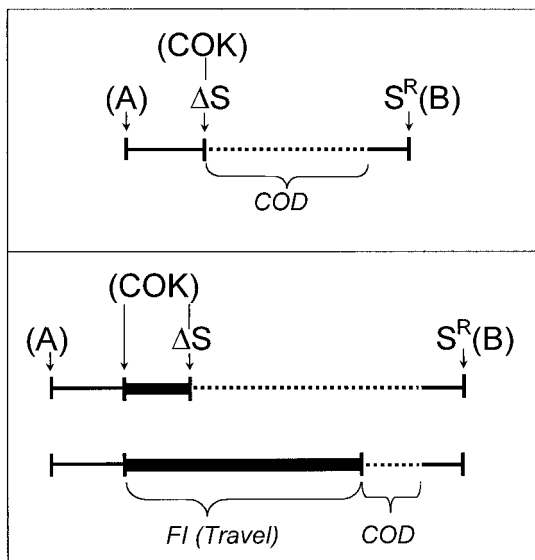


Fig. 1. The top panel shows the confounding effect between the delay between a response on one schedule and a reinforcer on the other and the delay between a changeover-produced stimulus change and a reinforcer that arises when the COD duration is manipulated. Items in parentheses with arrows refer to responses. A refers to the last response on Schedule A. COK is a response on the changeover key, and ΔS is the change of the main-key stimulus to that appropriate for Schedule B. $S^R(B)$ is a reinforcer delivery on Schedule B. Solid horizontal lines represent two intervals that are free to vary: (a) the interval between a response on Schedule A and a response on the changeover key, and (b) the interval between the end of the COD and a reinforced response on Schedule B. The dashed line represents the programmed duration of the COD. The bottom panel shows the procedure for Experiment 1. Symbols are as in the top panel. The heavy dark line between the two COK responses represents time in the FI travel requirement.

schedule and correlated stimulus (ΔS in Figure 1) and specifies a minimum interval (dashed line labeled COD in Figure 1) before a response on the changed-to schedule can be reinforced [$S^R(B)$ in Figure 1]. Increases in the COD duration increase the delay from the changeover-produced stimulus change to a reinforcer (referred to hereafter as the $\Delta S \rightarrow S^R$ delay) and the delay between the last response on one schedule (A in Figure 1) and a reinforcer delivery on the other (referred to hereafter as the $A \rightarrow S^R$ delay). The duration of the $\Delta S \rightarrow S^R$ delay depends on the programmed COD duration and the time between the end of the COD and a response on the changed-to schedule. The $A \rightarrow S^R$ delay depends on the time between the last peck on

one schedule and a peck to the changeover key, the programmed COD, and the time between the end of the COD and a response on the changed-to schedule. In two-key procedures, the COD typically is programmed from the first response on the changed-to alternative, and, again, increases in the programmed COD increase both delays. The confounding effect between the $\Delta S \rightarrow S^R$ delay and the $A \rightarrow S^R$ delay suggests that changeover rates may be controlled by either or both of these delays.

Changes in the $\Delta S \rightarrow S^R$ delay might control changeover rates to some extent, because as noted by Findley (1958), changing over may be maintained in part by the conditioned reinforcing effects of main-key stimulus changes (see also Kelleher & Gollub, 1962, pp. 573–575). Longer $\Delta S \rightarrow S^R$ delays would attenuate the reinforcing effects of such stimulus changes (cf. Fantino, 1969, 1977) and decrease changing over. Conversely, support for the control of changeover rates by the $A \rightarrow S^R$ delay is provided by the effects of travel requirements on changing over.

Travel requirements are contingencies placed on changeover behavior by separating the alternatives spatially or placing partitions between operanda to make changing over more difficult (Aparicio & Baum, 1997; Baum, 1982). Travel requirements also have been arranged by requiring the completion of schedule requirements on the changeover key for a changeover to occur (e.g., Davison, 1991; McCarthy, Voss, & Davison, 1994). Travel requirements and CODs have been considered functionally equivalent (Baum, 1982; cf. Stubbs, Pliskoff, & Reid, 1977) because as travel requirements increase, rates of changing over decrease and dwell times increase (e.g., Aparicio & Baum, 1997; Baum, 1982; Davison, 1991; Davison & McCarthy, 1994; McCarthy et al., 1994).

The effects of travel requirements have been attributed to the punishing effects of the work requirements they arrange (Baum, 1982). By comparing the effects of fixed-ratio, fixed-interval (FI), and fixed-time-in-blackout schedules on the changeover key, however, McCarthy et al. (1994) demonstrated that dwell times depended on the time taken to complete the changeover schedule rather than the specific schedule requirements (i.e., work requirements) for changing

over. Similarly, Aparicio and Baum (1997) found that locomotor travel requirements and random-interval travel requirements that required similar amounts of time to complete similarly affected dwell times. These data suggest that travel requirements may affect changing over by increasing the total time between a response on one alternative and a reinforcer on the other (i.e., increasing the $A \rightarrow S^R$ delay; but see Davison, 1991, for a punishment account based on time taken to change over). Unlike the COD, increases in travel requirements increase the delay between the last response on one schedule and the presentation of the stimulus conditions (i.e., S) associated with the other schedule. The role of the $\Delta S \rightarrow S^R$ delay in the effects of travel requirements is unknown because it is left unspecified and previously has not been recorded.

Although it appears that the delay to the first postchangeover reinforcer is important in concurrent-schedule performance, the mechanism by which this delay has its effects is not clear. The delay to reinforcement following a changeover may affect changeover rates through either or both of two functions: (a) by changing the delay to reinforcement associated with leaving one alternative to obtaining a reinforcer on the other (i.e., $A \rightarrow S^R$ delay is of primary importance) and (b) by changing the delay to reinforcement associated with the presentation of the stimuli associated with the changed-to schedule (i.e., $\Delta S \rightarrow S^R$ delay is of primary importance). The confounding effect between the $\Delta S \rightarrow S^R$ delay and the $A \rightarrow S^R$ delays when CODs are used and the unspecified $\Delta S \rightarrow S^R$ delays arranged by travel requirements prohibit conclusions about the relative contributions of the $A \rightarrow S^R$ and $\Delta S \rightarrow S^R$ delays to controlling changeover rates. The present experiments, therefore, analyzed the independent effects of both the $A \rightarrow S^R$ and $\Delta S \rightarrow S^R$ delays on changing over.

EXPERIMENT 1

This experiment examined the effects of varying the $\Delta S \rightarrow S^R$ delay while the duration of the $A \rightarrow S^R$ delay remained constant. Although neither delay can be manipulated directly, the present experiment used the combination of a COD and an FI travel requirement to vary the $\Delta S \rightarrow S^R$ delay while a

roughly constant $A \rightarrow S^R$ delay was maintained. In this manner, the independent effects of the $\Delta S \rightarrow S^R$ delay could be assessed.

METHOD

Subjects

Four retired breeder male White Carneau pigeons maintained at 80% of free-feeding weights were used. Pigeons were individually housed in a temperature-controlled colony under a 12:12 hr light/dark cycle and had free access to water and grit. Each pigeon had a history of responding on several schedules of reinforcement.

Apparatus

A sound-attenuating operant conditioning chamber (28 cm wide, 31 cm long, 32 cm high) was used. Two response keys (2 cm diameter) were 5.5 cm from either side wall of the chamber, 15 cm apart (center to center), and 23.5 cm from the floor. Each key required a force of approximately 0.15 N to operate and could be transilluminated. Reinforcement consisted of 4.5-s presentations of mixed grain from a grain hopper. The hopper was accessible, when raised, through an aperture (6 cm wide by 4.5 cm tall) located on the midline of the work panel with its center 10 cm from the floor. A 28-V DC clear bulb illuminated the aperture, and all other lights were extinguished when the hopper was operated. General illumination was provided by two 28-V DC clear bulbs mounted on the ceiling in the rear of the chamber. A ventilation fan and white noise masked extraneous noise. Contingencies were programmed and data recorded with a microcomputer using Med-PC® software.

Procedure

The pigeons were trained to respond on concurrent variable-interval (VI) 3-min VI 3-min schedules using a changeover-key procedure (Findley, 1958) with no COD. All VI schedules in this and subsequent experiments were composed of 20 intervals and were constructed according to the constant probability distribution described by Fleshler and Hoffman (1962). In the changeover-key procedure, one VI 3-min schedule was correlated with a red main key (left key) and the other with a green main key. The changeover key (right key) was white, and a response to

the changeover key darkened it immediately and changed the schedule on the main key. The changeover keylight then was illuminated after the first main-key response. When changeover rates and relative time distributions appeared to be stable (see below), a response-initiated FI 1-s travel requirement was introduced on the changeover key with an 8-s COD following the completion of the FI requirement. The bottom panel of Figure 1 shows a diagram of the two conditions of the experiment. The first response on the changeover key (left arrow from COK in Figure 1) started the FI travel requirement and darkened the main key. The main key was reilluminated with the changed-to schedule stimulus (ΔS in Figure 1) following the first response on the changeover key after the FI had lapsed (right arrow from COK in Figure 1). The COD was timed from the completion of the FI travel requirement on the changeover key. The first main-key response could be reinforced [$S^R(B)$ in Figure 1] if the COD had expired. Responses during the FI travel requirement, COD, and to dark keys had no programmed effect. Subsequently, conditions were changed such that an FI 8-s travel requirement and a 1-s COD were in effect. Subjects then were returned to the FI 1-s travel and 8-s COD condition.

Each condition was in effect for a minimum of 15 sessions and until responding was stable. Table 1 shows the number of sessions in each condition. Stability was based on visual inspection of changeover rates (total changeovers divided by total time) and the fulfillment of a mathematical criterion on relative time distributions (proportion of time on the red schedule). Stability in relative time distributions was defined as the occurrence of five, not necessarily consecutive, 5-day relative time distribution medians that did not differ by more than 0.05 (cf. Davison & McCarthy, 1988). Sessions occurred at approximately the same time each day, 7 days per week, and ended after 30 reinforcer deliveries.

RESULTS

Table 1 shows relative time spent on the schedule correlated with the red main key (red time divided by total time). Deviations of relative time distributions from .5 reflect bias for one main-key schedule and would be expected to decrease changeover rates. The

Table 1

Sequence of conditions, number of sessions, relative time in red, and the proportion of postchangeover reinforcers in Experiment 1. FI and COD durations are given in seconds. Relative time and proportion of postchangeover reinforcers are means of the last five sessions of each condition. Standard deviations appear in parentheses.

Subject	Condition	Sessions	Relative time red	Proportion post-CO-reinforcers
442	No FI no COD	46	.49 (.01)	.85 (.07)
	FI 1 COD 8	20	.49 (.02)	.65 (.11)
	FI 8 COD 1	33	.51 (.01)	.71 (.11)
	FI 1 COD 8	17	.49 (.03)	.69 (.08)
372	No FI no COD	22	.50 (.02)	.97 (.03)
	FI 1 COD 8	23	.55 (.02)	.85 (.10)
	FI 8 COD 1	39	.47 (.02)	.87 (.05)
	FI 1 COD 8	15	.59 (.02)	.70 (.06)
810	No FI no COD	55	.49 (.02)	.87 (.06)
	FI 1 COD 8	15	.48 (.01)	.62 (.09)
	FI 8 COD 1	30	.40 (.02)	.59 (.11)
	FI 1 COD 8	27	.55 (.02)	.65 (.06)
891	No FI no COD	32	.51 (.02)	.91 (.05)
	FI 1 COD 8	16	.47 (.07)	.52 (.10)
	FI 8 COD 1	28	.47 (.02)	.58 (.10)
	FI 1 COD 8	15	.57 (.04)	.56 (.07)

absence of any systematic deviations from .5 reflects the absence of a systematic bias that could influence changeover rates across conditions.

Table 1 also shows the proportion of postchangeover reinforcers. Reinforcers were considered to be postchangeover reinforcers if they were delivered for the first main-key response after a COD had lapsed. For conditions with no COD, reinforcers delivered for the first response after a changeover-key response were considered to be postchangeover reinforcers. With no FI and no COD in effect, approximately 90% of all reinforcers were postchangeover reinforcers. The other conditions, in which the relative durations of the FI and COD were varied, produced no systematic changes in the proportion of postchangeover reinforcers. Across pigeons, 52% to 87% of all reinforcers were delivered after a changeover when the FI travel requirement and COD were in effect.

To determine if the different combinations of CODs and FI travel requirements successfully manipulated the $\Delta S \rightarrow S^R$ delay while the $A \rightarrow S^R$ delay was kept constant, the distributions of both delays were examined. Figure 2 shows box plots of the distributions of $A \rightarrow S^R$ and $\Delta S \rightarrow S^R$ delays. Both delays are presented

only for postchangeover reinforcers. Median $A \rightarrow S^R$ delays were shorter when no FI and no COD were in effect than in the other conditions. Median $A \rightarrow S^R$ delays were similar with overlapping interquartile ranges in the FI 1-s COD 8-s and FI 8-s COD 1-s conditions. Median $\Delta S \rightarrow S^R$ delays were short when there was a 1-s COD or no COD in effect and longer when the COD was 8 s. Interquartile ranges did not overlap for the $\Delta S \rightarrow S^R$ delay when the COD was short and when it was long. Thus, the $\Delta S \rightarrow S^R$ delay was successfully manipulated independently of the duration of the $A \rightarrow S^R$ delay. The distributions of both delays were skewed toward longer durations, and for this reason, the median was used as the measure of central tendency in subsequent analyses.

Figure 3 shows mean changeover rates (total changeovers divided by session time minus reinforcement time minus time in FI) for the last five sessions of each condition. Changeover rates were highest when no FI and no COD were in effect and generally lower in the other conditions. For all 4 pigeons, changeover rates were slightly higher when the $\Delta S \rightarrow S^R$ delay was short than when it was long. For Pigeons 442, 891, and 810 the difference between the long and short $\Delta S \rightarrow S^R$ delay conditions was less than one changeover per minute. The difference between these conditions was larger for Pigeon 372, but this difference in changeover rates was small relative to that obtained when neither an FI nor a COD was in effect.

DISCUSSION

Decreasing the COD, and thus the $\Delta S \rightarrow S^R$ delay, increased changeover rates only slightly when the delay between a response on one schedule and a reinforcer on the other (the $A \rightarrow S^R$ delay) was constant. Although the increase in changeover rates produced by the short $\Delta S \rightarrow S^R$ delay was small, it was reliable across subjects. Increases in the $A \rightarrow S^R$ delay, however, produced large decreases in changeover rates.

The present experiment examined the $A \rightarrow S^R$ delay at only two values: the short delay produced by the conditions with no FI travel requirement or COD, and the long delay produced by the other conditions. Stubbs et al. (1977) reviewed previous studies and described the relation between *programmed* COD

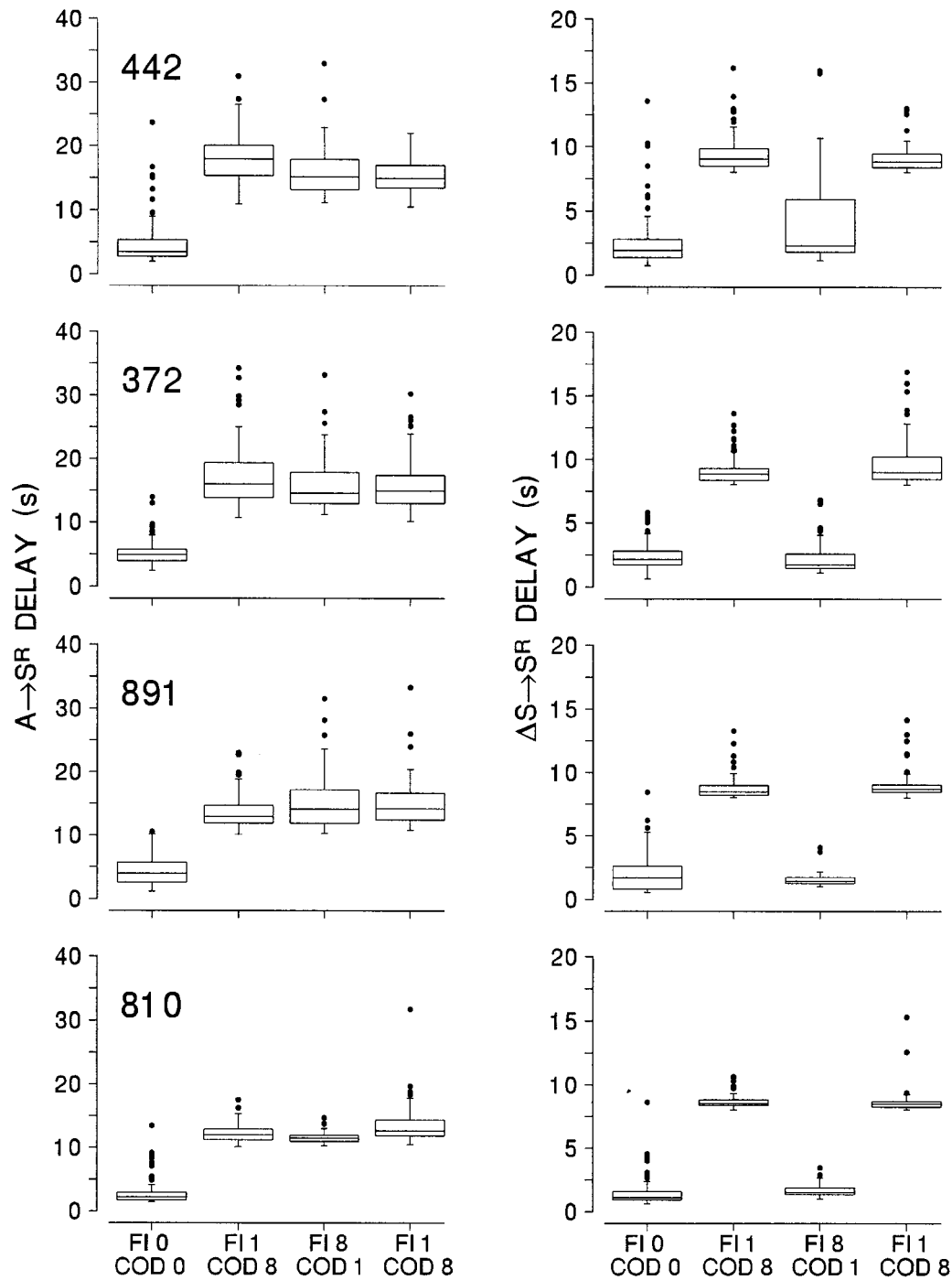


Fig. 2. Box plots of the distributions of $A \rightarrow SR$ and $\Delta S \rightarrow SR$ delays from the last 5 days of each condition of Experiment 1. The center lines of the boxes represent the median, and the upper and lower edges of the boxes correspond to the 75th and 25th percentiles, respectively. Vertical bars extend to the highest and lowest values in the distributions that fall within 1.5 times the interquartile range. Filled circles represent delays falling outside the vertical bars.

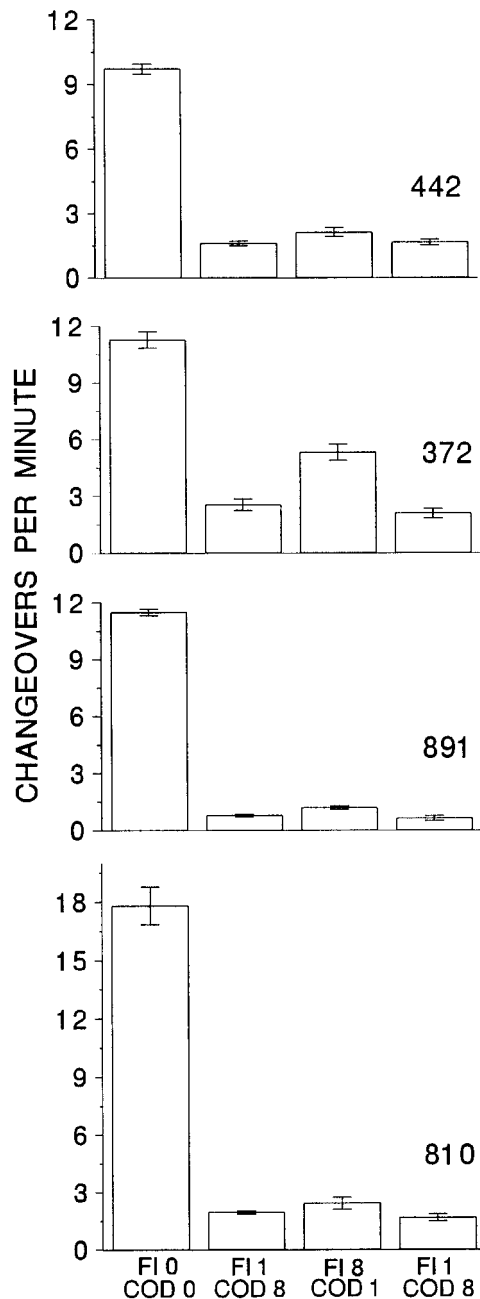


Fig. 3. Changeover rates in each condition. Data represent means for the last 5 days of each condition, and vertical bars are ± 1 SD.

duration or travel requirements and inter-changeover interval (i.e., the inverse of changeover rate) as a power function. The function described by Stubbs et al. may reflect changes in the $A \rightarrow S^R$ delay produced by

increases in either programmed CODs or travel requirements. However, an examination of the relation between changeover rates and the $A \rightarrow S^R$ delay requires comparing the effects of a range of $A \rightarrow S^R$ delays on changeover rates. Also, the small effect of the $\Delta S \rightarrow S^R$ delay invites additional analyses to determine whether this delay may affect changeover rates independently of the $A \rightarrow S^R$ delay. A further test of the role of each delay would be to compare the effects of the $A \rightarrow S^R$ delay when increases in this delay are associated with increases in the $\Delta S \rightarrow S^R$ delay and when changes in the $A \rightarrow S^R$ delay are not associated with changes in the $\Delta S \rightarrow S^R$ delay.

The smallness of the effects of the $\Delta S \rightarrow S^R$ delay furthermore may have been an artifact of the 9-s $A \rightarrow S^R$ delay, because this delay may have suppressed changeover rates to such an extent that the effect of the $\Delta S \rightarrow S^R$ delay was obscured. A comparison of the effects of different $\Delta S \rightarrow S^R$ delays when the $A \rightarrow S^R$ delay is held constant at values shorter than in the present experiment would assess this possibility.

EXPERIMENT 2

Changeover rates were examined over a range of $A \rightarrow S^R$ delays. The $A \rightarrow S^R$ delay was varied in two ways. First, the $A \rightarrow S^R$ delay was manipulated by varying the duration of the $\Delta S \rightarrow S^R$ delay (by varying the COD). Second, it was manipulated by varying the FI travel requirement while the $\Delta S \rightarrow S^R$ delay was held approximately constant.

METHOD

Subjects, Apparatus, and Procedure

The subjects and apparatus were those used in Experiment 1.

Procedural details were as described in Experiment 1 except that the FI travel requirement and COD durations were varied. The FI and COD durations used to produce the different $A \rightarrow S^R$ delays were FI 1 s COD 1 s, FI 1 s COD 2 s, FI 2 s COD 1 s, FI 4 s COD 1 s, and FI 1 s COD 4 s. These conditions also allowed an assessment of the effects of increases in the $A \rightarrow S^R$ delay that were associated with increases in the $\Delta S \rightarrow S^R$ delay (FI 1 s COD 1 s, FI 1 s COD 2 s, and FI 1 s COD 4 s) and increases in the $A \rightarrow S^R$ delay that were not associated with increases in the

Table 2

Sequence of conditions, number of sessions, relative time in red, proportion of postchangeover reinforcers, and changeover rates in Experiment 2. Relative time, proportion of postchangeover reinforcers, and changeover rates are means of the last five sessions of each condition. Standard deviations appear in parentheses.

Subject	FI (s)	COD (s)	Sessions	Relative time red	Proportion post-CO reinforcers	CO/min
442	1	4	16	.48 (.01)	.79 (.02)	2.91 (0.19)
	4	1	20	.48 (.02)	.73 (.09)	2.74 (0.05)
	1	1	31	.49 (.03)	.79 (.05)	5.65 (0.30)
	2	1	22	.48 (.02)	.74 (.14)	4.26 (0.33)
372	1	2	19	.47 (.01)	.71 (.06)	4.56 (0.30)
	4	1	38	.46 (.01)	.89 (.06)	7.46 (0.48)
	1	4	25	.52 (.02)	.68 (.05)	3.59 (0.25)
	1	1	19	.49 (.02)	.83 (.04)	7.20 (0.31)
810	1	2	24	.53 (.02)	.79 (.07)	5.39 (0.11)
	2	1	17	.51 (.02)	.83 (.07)	6.75 (0.30)
	1	4	20	.55 (.04)	.73 (.08)	2.51 (0.23)
	4	1	21	.51 (.02)	.69 (.05)	3.85 (0.40)
891	1	1	35	.47 (.02)	.73 (.10)	5.35 (0.56)
	2	1	15	.51 (.01)	.77 (.04)	5.96 (0.26)
	1	2	15	.48 (.02)	.70 (.04)	4.91 (0.57)
	4	1	19	.48 (.03)	.61 (.05)	1.90 (0.15)
891	1	4	21	.56 (.03)	.60 (.09)	0.98 (0.09)
	1	1	44	.58 (.05)	.68 (.07)	2.81 (0.47)

$\Delta S \rightarrow S^R$ delay (FI 1 s COD 1 s, FI 2 s COD 1 s, and FI 4 s COD 1 s). These combinations of FI and COD supplemented those of Experiment 1 with minimum $A \rightarrow S^R$ delays of 5 s (FI 1 s COD 4 s and FI 4 s COD 1 s) and 3 s (FI 1 s COD 2 s and FI 2 s COD 1 s). Sessions occurred 7 days per week and ended after 30 reinforcers. The stability criteria were as in Experiment 1. The order of conditions and the number of sessions in each are shown in Table 2. Pigeon 891 developed a facial tumor and was removed from the experiment before completing the FI 1-s COD 2-s and FI 2-s COD 1-s conditions.

RESULTS

Table 2 shows the proportion of time spent in the presence of the schedule correlated with the red main key. Relative time distributions were near .5 in all conditions, suggesting that there was no systematic bias between conditions. Table 2 also shows the proportion of postchangeover reinforcers. Across pigeons, the proportion of postchangeover reinforcers was between .60 and .89 and did not vary systematically across conditions. For Pigeon 372 the proportion of postchangeover reinforcers was lower in the FI 1-s COD 4-s condition and higher in the

FI 4-s COD 1-s condition than in the other conditions.

Figure 4 shows box plots of the $A \rightarrow S^R$ and $\Delta S \rightarrow S^R$ delays from the last five sessions of each condition for postchangeover reinforcers (as in Figure 2). In general, $A \rightarrow S^R$ delays increased with increases in either FI or COD durations. The $\Delta S \rightarrow S^R$ delay was usually shorter in conditions in which the COD was 1 s than those in which the COD was longer (i.e., 2 s or 4 s) and was longest when the COD was 4 s.

Figure 5 shows the relation between median $A \rightarrow S^R$ delay and mean changeover rate in the last five sessions of each condition of Experiments 1 and 2. Changeover rates decreased with increases in the $A \rightarrow S^R$ delay. The linear equation for the fitted lines in logarithmic coordinates suggests a power function (i.e., $y = bx^{-a}$) in arithmetic coordinates (cf. Stubbs et al., 1977). The fit of the functions is good (96% or more of the variance accounted for) for 3 of 4 pigeons. The fit is poorer for Pigeon 372, for which $\Delta S \rightarrow S^R$ delay had the largest effect, with only 72% of the variance accounted for.

Conditions in which the $A \rightarrow S^R$ delay was varied by changing the $\Delta S \rightarrow S^R$ delay (i.e., the COD was manipulated) are represented in

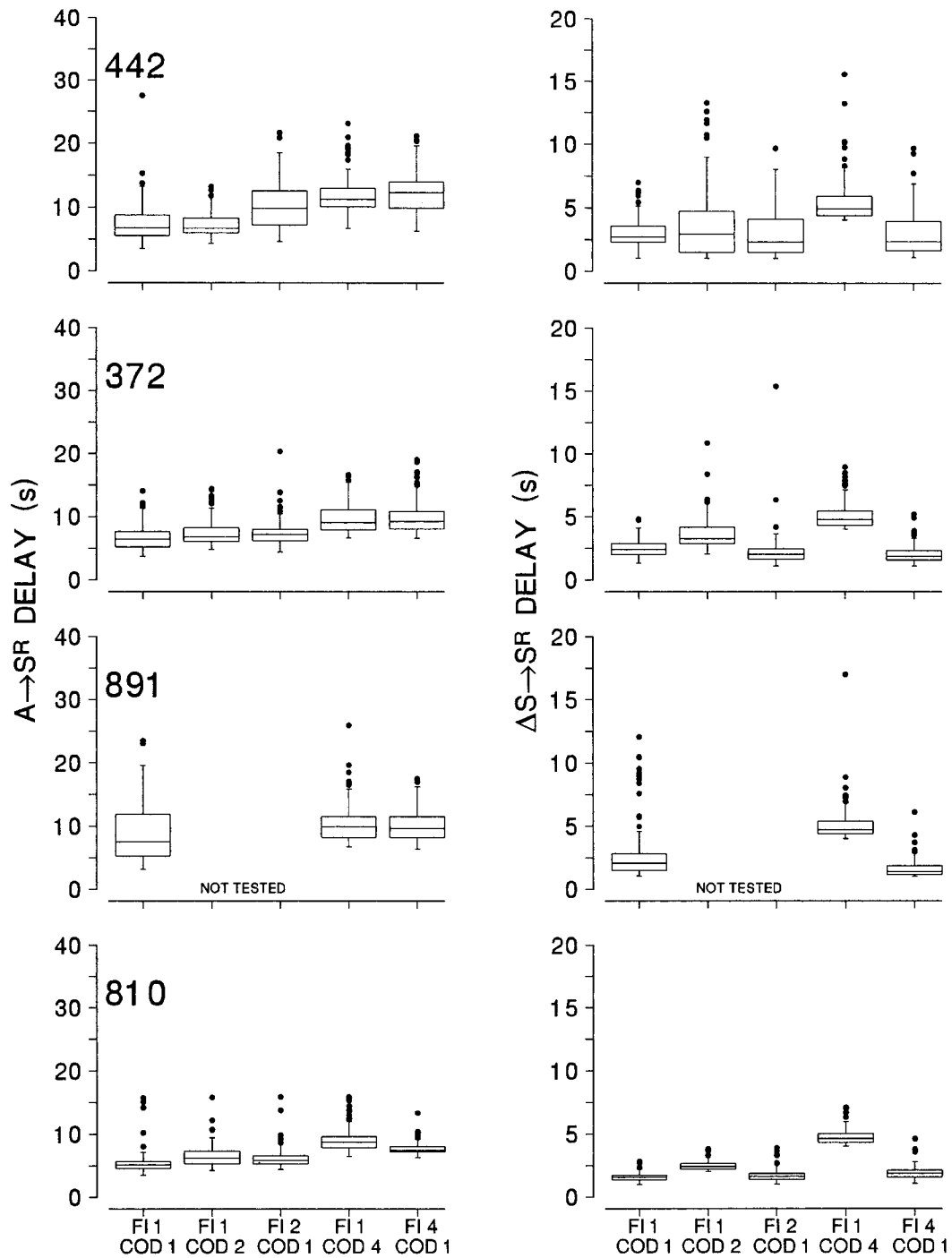


Fig. 4. Box plots of the distributions of $A \rightarrow SR$ and $\Delta S \rightarrow SR$ delays from the last 5 days of each condition of Experiment 2. Data are presented as in Figure 2.

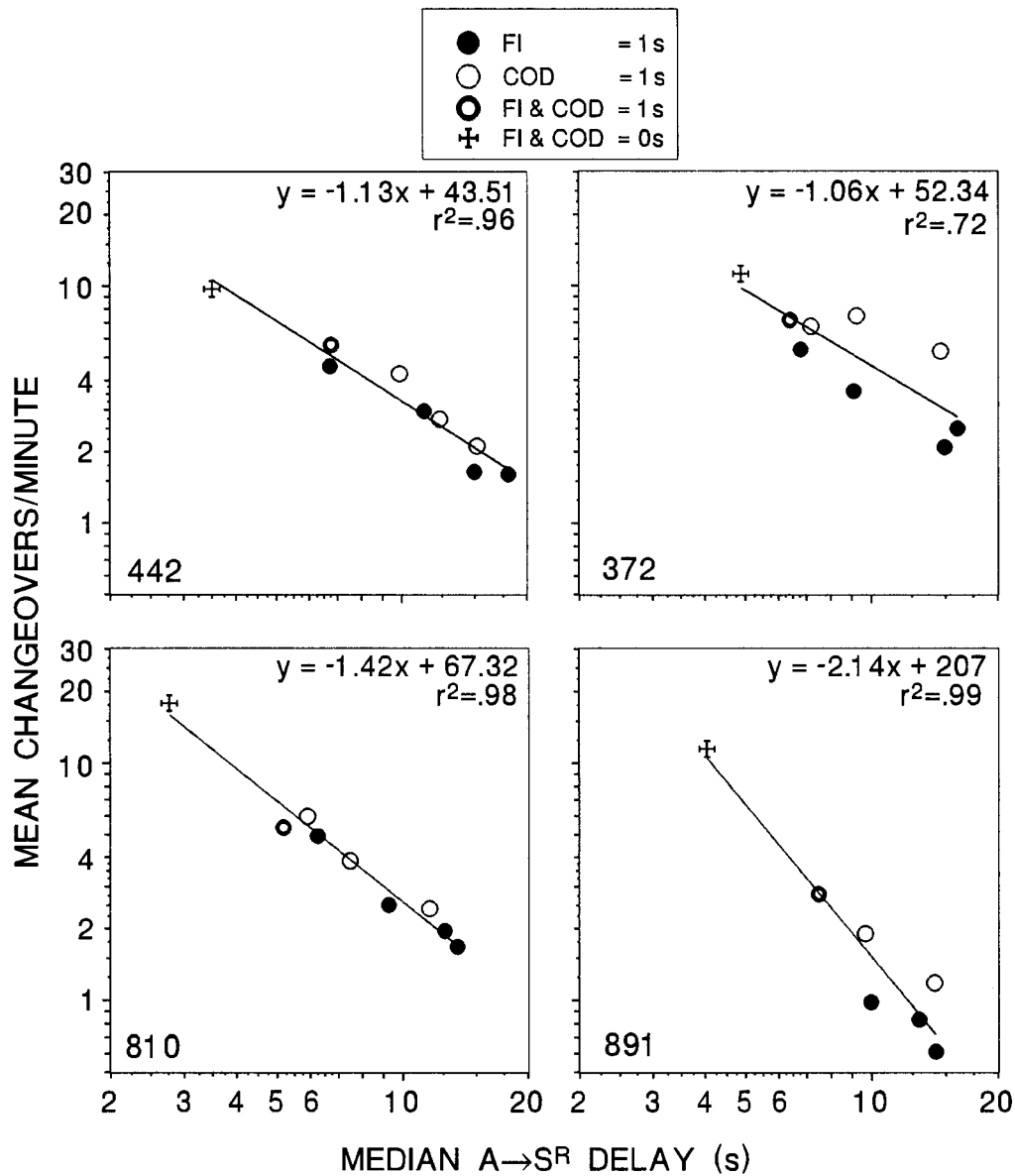


Fig. 5. The relation between mean changeover rates and the median obtained delay between a response on one schedule and a reinforcer on the other (i.e., $A \rightarrow S^R$ delay). Data are presented from Experiments 1 and 2 and are from the last five sessions of each condition. Both axes are logarithmic, and fitted lines represent least squares regression lines for the function presented in the top right of each panel. See text for details.

Figure 5 by filled circles (see also the partially filled symbol that represents the FI 1-s COD 1-s condition). This manipulation was similar to those in previous research in which the COD was manipulated (e.g., Bourland & Miller, 1978; Pliskoff, 1971; Shull & Pliskoff, 1967; Temple et al., 1995). Conditions in which the $\Delta S \rightarrow S^R$ delay (i.e., the COD duration) was

constant and the $A \rightarrow S^R$ delay was varied by changes in the FI travel requirement are represented by open circles (see also the partially filled symbol that represents the FI 1-s COD 1-s condition). Changeover rates decreased with increases in the $A \rightarrow S^R$ delay when the $\Delta S \rightarrow S^R$ delay was held approximately constant. The marginally higher changeover

Table 3

Multiple regression analyses of changeover rates as a function of A→S^R delay duration and type of COD for Experiments 1 and 2.

Subject	r^2	SE	F	p	Coefficients					
					A→S ^R delay			COD type		
					β	t	p	β	t	p
442	.94	.05	32.45	.003	-0.95	-7.84	.001	-0.26	-2.14	.099
372	.92	.07	21.69	.007	-0.58	-3.91	.017	-0.68	-4.61	.010
891	.99	.03	75.24	.013	-0.54	-6.65	.022	-0.76	-9.27	.011
810	.98	.04	103.82	.000	-0.93	-12.74	.000	-0.14	-1.90	.130

Note. $F(2, 4)$ for all pigeons except Pigeon 891, for which $F(2, 2)$. For all t tests $t(4)$ except for Pigeon 891, for which $t(2)$. $\alpha = .05$ for all statistical tests.

rates obtained at similar A→S^R delays when the $\Delta S \rightarrow S^R$ delay was short (most notable for Pigeons 372 and 891) are represented by the tendency for open circles to sit above filled circles at similar obtained A→S^R delays (see Table 2 for changeover rates in each condition of Experiment 2). The size of this effect appears larger than in Figure 3 as a result of the logarithmic y axis.

To further examine the contributions of the $\Delta S \rightarrow S^R$ and A→S^R delays to changeover rates, a multiple regression with two independent variables (A→S^R delay and type of COD) was performed on the data of individual pigeons. Type of COD, either short or long, was entered as a categorical variable, and conditions in which the FI travel requirement and COD were equal (FI 0 s COD 0 s and FI 1 s COD 1 s) were dropped because of their ambiguous status in the categorical variable. Changeover rates and A→S^R delay durations were transformed to logarithms prior to the multiple regression. Table 3 shows the outcome of the multiple regression analysis. First, the overall multiple regression coefficient (r^2) was significant for each pigeon. Second, examination of the standardized regression coefficients (β) for A→S^R delay and type of COD revealed that A→S^R delay duration contributed significantly to the prediction of changeover rates for every pigeon, but type of COD contributed significantly only for Pigeons 372 and 891.

DISCUSSION

Changeover rates decreased as a negative power function of the A→S^R delay. Although the negative power function accounted for the data well, the slightly higher changeover

rates obtained in Experiment 1 with shorter $\Delta S \rightarrow S^R$ delays were replicated at different A→S^R delays. The negative power function describing the relation between changeover rates and the A→S^R delay is similar to the relation previously observed between inter-changeover intervals and programmed COD duration or travel requirement (Stubbs et al., 1977). Thus, the power function described by Stubbs et al. may reflect changes in the A→S^R delay produced by changes in the programmed COD duration or travel requirement.

Although the $\Delta S \rightarrow S^R$ delay produced some effect, this effect was reliable for only 2 pigeons and was small relative to the effect of the A→S^R delay and to previously noted effects of changes in the programmed COD duration (e.g., Pliskoff, 1971; Shull & Pliskoff, 1967; Stubbs et al., 1977; Temple et al., 1995). In previous experiments, when a COD near 1 s was in effect (i.e., the $\Delta S \rightarrow S^R$ was short), changeover rates typically were similar to those when no COD was in effect and were lower when a longer COD was in effect (i.e., the $\Delta S \rightarrow S^R$ was long; e.g., Bourland & Miller, 1978; Shull & Pliskoff, 1967; Temple et al., 1995). The present findings suggest that decreases in changeover rates obtained with increases in COD duration largely reflect the effects of changes in the A→S^R delay.

EXPERIMENT 3

The effects of the A→S^R delay in Experiments 1 and 2 were consistent with the effects of increases in travel requirements on changing over. Longer travel requirements arrange longer minimum A→S^R delays and decrease

changeover rates. As opposed to CODs, which specify a minimum $\Delta S \rightarrow S^R$ delay, travel requirements leave the $\Delta S \rightarrow S^R$ delay unspecified, and this delay previously has not been recorded. Although travel requirements and CODs have been considered functionally equivalent in their effects on changing over (Baum, 1982; Davison, 1991; Pliskoff, Cicerone, & Nelson, 1978; Stubbs et al., 1977), they produce differences in both local response patterns and matching. For example, Pliskoff et al. found that response rates were elevated for a longer time following a changeover when a 2-s COD was in effect than when a fixed-ratio (FR) 5 on a changeover key was required to change over. Similarly, many studies have found elevated response rates during the COD (e.g., Baum, 1974; Menlove, 1975; Pliskoff, 1971; Shahan & Lattal, 1998; Silberberg & Fantino, 1970). Such elevated rates may contribute disproportionately to relative response rates on the leaner alternative and thus account for the finding that increases in travel requirements produce overmatching but increases in COD duration do not (e.g., Baum, 1982; Dreyfus, DePorto-Callan, & Pesillo, 1993; Pliskoff et al., 1978; Temple et al., 1995).

Although the $\Delta S \rightarrow S^R$ delay had little effect on changeover rates in Experiments 1 and 2, it is likely that this delay contributes to the elevated response rates often observed during the COD, and thus to undermatching. Although Pliskoff et al. (1978) showed that FR travel requirements and CODs produce different local patterns of responding following a changeover, they compared local response patterns for only one travel requirement and COD duration. Experiment 3 examined the effects of a range of durations of equal and independently arranged FI travel requirements and COD durations on changeover rates and local response patterns following a changeover.

METHOD

Subjects

Three retired breeder male White Carneau pigeons (not those from Experiments 1 and 2) were maintained at 80% of free-feeding weights. Pigeons were individually housed in a temperature-controlled colony under a 12:12 hr light/dark cycle and had free access

to water and grit. Each pigeon had a history of responding on several schedules of reinforcement.

Apparatus

An operant conditioning chamber with internal dimensions of 33 by 30 by 30 cm was used. General illumination was provided by two 28-V DC bulbs located behind an aperture (10 cm diameter) covered by translucent plastic and located 3 cm above the floor and 9 cm to the right of the midline. Two response keys (2 cm diameter) were used. One key (the changeover key) was mounted 7.5 cm from the right side wall, and the other key (the main key) was mounted 16.5 cm from either side wall of the chamber. Both keys were located 25 cm from the floor and required a force of approximately 0.15 N to operate. The changeover keylight could be lit green, and the main keylight could be lit either amber or blue with 28-V DC bulbs. Reinforcement was 3-s presentations of mixed grain from a grain hopper. The hopper was accessible, when raised, through an aperture (4.5 cm by 6 cm) located on the midline of the work panel with its center 9.5 cm from the floor. A clear 28-V DC bulb illuminated the aperture, and all other lights were extinguished when the hopper was operated. Ventilation was provided through a hole (5 cm diameter) in the rear of the chamber, and white noise masked extraneous noise. Contingencies were programmed on a microcomputer using Med-PC® software.

Procedure

The pigeons initially were trained to respond on concurrent VI 3-min VI 3-min schedules using a changeover-key procedure and no COD or FI travel requirement. The changeover key was lit green, and the main key was either amber or blue. Three COD durations and FI travel requirements (1 s, 4 s, and 8 s) were examined across conditions. Either a COD or an FI travel requirement was in effect, but not both. Table 4 shows the order of conditions and the number of sessions for each subject in each condition. FI travel requirements and CODs were programmed as in Experiments 1 and 2. When a COD was in effect, the first response on the changeover key produced the main-key schedule alternation and the correlated stimulus change

Table 4

Sequence of conditions, number of sessions, relative time in amber, proportion of postchangeover reinforcers, and changeover rates in Experiment 3. Data are presented as in Tables 1 and 2.

Subject	Condition	Sessions	Relative time amber	Proportion post-CO reinforcers	CO/min
840	No FI no COD	25	.54 (.02)	.96 (.03)	14.96 (0.76)
	COD 1	28	.62 (.01)	.88 (.03)	13.42 (0.11)
	FI 1	45	.52 (.02)	.99 (.01)	11.36 (0.61)
	FI 4	20	.53 (.01)	.91 (.08)	6.56 (0.62)
	COD 4	19	.66 (.03)	.69 (.04)	3.26 (0.38)
	COD 8	20	.70 (.04)	.65 (.07)	1.76 (0.16)
	FI 8	17	.58 (.04)	.75 (.11)	2.93 (0.93)
742	No FI no COD	22	.51 (.03)	.71 (.08)	10.17 (0.76)
	FI 1	32	.52 (.02)	.69 (.05)	6.26 (0.42)
	COD 1	21	.45 (.01)	.78 (.05)	9.07 (0.27)
	FI 4	22	.61 (.02)	.58 (.08)	2.75 (0.35)
	COD 4	20	.51 (.07)	.56 (.09)	2.27 (0.36)
	FI 8	15	.49 (.05)	.46 (.07)	1.02 (0.15)
	COD 8	15	.55 (.04)	.59 (.11)	1.38 (0.18)
819	No FI no COD	67	.48 (.02)	.73 (.08)	13.15 (0.75)
	FI 1	32	.52 (.11)	.65 (.12)	6.12 (0.81)
	COD 1	24	.53 (.05)	.65 (.02)	7.65 (0.49)
	COD 4	24	.35 (.03)	.67 (.09)	4.16 (0.49)
	FI 4	17	.41 (.03)	.73 (.09)	5.33 (0.31)
	FI 8	17	.32 (.04)	.62 (.11)	1.80 (0.25)
	COD 8	15	.51 (.07)	.72 (.08)	2.13 (0.13)

and started the COD. When the FI travel requirement was in effect, the first response on the changeover key started the FI, and a response after the FI had lapsed produced the schedule change. The first main-key response therefore could be reinforced. The stability criteria were as in Experiment 1. Sessions occurred 7 days per week and ended after 30 reinforcers.

RESULTS

The relative amount of time spent in the presence of the schedule correlated with the amber main key (amber time divided by total time) is shown in Table 4. Differences in the relative time spent in amber occurred for each subject across conditions. For Pigeon 840, COD conditions consistently produced a bias for the amber main key. For Pigeon 742, the differences in relative time were inconsistent across FI and COD conditions, with standard deviations overlapping. As a result, changeover rates probably were not systematically affected by bias for Pigeon 742. For Pigeon 819, the relative time spent in the presence of amber was lower for the COD and FI conditions greater than 1 s than for those 1 s or less, except for COD 8 s.

Table 4 also shows the proportion of postchangeover reinforcers. The proportion of postchangeover reinforcers was higher for Pigeon 840 than for the other pigeons. Also for Pigeon 840, more reinforcers were delivered after a changeover in the FI conditions than in the COD conditions. For Pigeon 742, the proportion of postchangeover reinforcers was higher when a COD was in effect in the 1-s and 8-s conditions, but not in the 4-s conditions. The proportion of postchangeover reinforcers did not differ systematically across conditions for Pigeon 819.

Figure 6 shows box plots of the $A \rightarrow S^R$ and $\Delta S \rightarrow S^R$ delays for the last five sessions of each condition for postchangeover reinforcers. The left panel shows that $A \rightarrow S^R$ delays were skewed toward longer values and increased with increases in the programmed duration of the FI and COD. The $A \rightarrow S^R$ delay was longer for FI conditions than for COD conditions of the same programmed duration. These differences were especially pronounced for Pigeon 840. The right panel shows that the $\Delta S \rightarrow S^R$ delay remained relatively constant across the different FI conditions but increased with COD increases.

Changeovers per minute in each condition

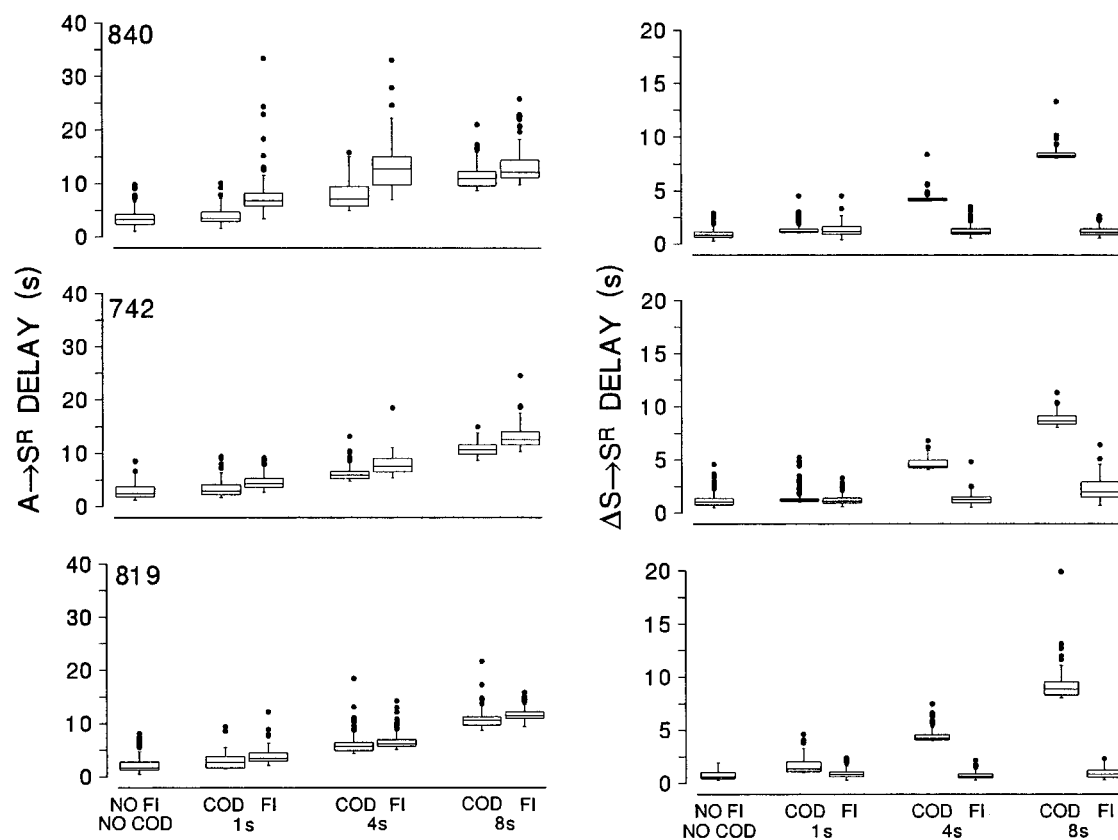


Fig. 6. Box plots of the distributions of $A \rightarrow S^R$ and $\Delta S \rightarrow S^R$ delays from the last 5 days of each condition of Experiment 3. Data are presented as in Figure 2.

are shown in Table 4. Changeover rates usually decreased with increases in the $A \rightarrow S^R$ delay. Changeover rates were not systematically different for FI and COD conditions even though the $A \rightarrow S^R$ delay was consistently longer in the FI conditions. For Pigeon 840, changeover rates were higher in the FI 4-s condition than in the COD 4-s condition, even though the $A \rightarrow S^R$ delay was considerably longer in the FI 4-s condition. A similar but smaller effect occurred with the other 2 pigeons. This effect was consistent only when the FI and COD were nominally 4 s and may be more pronounced for Pigeon 840 as a result of the stronger bias in relative time distributions and the higher proportion of postchangeover reinforcers (see Table 4) in the 4-s conditions. For Pigeon 840, changeover rates also were lower in some COD conditions than in FI conditions that produced similar $A \rightarrow S^R$ delays (e.g., the FI 1-s vs. the COD 4-s condition and the FI 4-s vs. the COD

8-s condition). However, in these cases the differences in schedule bias and the proportion of postchangeover reinforcers noted above also were present.

Figure 7 shows the relation between mean changeovers per minute and the $A \rightarrow S^R$ delay for the last five sessions of each condition. Changeover rates decreased with increases in the $A \rightarrow S^R$ delay. The negative power function describes the data well, with the poorest fit occurring for Pigeon 840 ($r^2 = .74$), for which the $\Delta S \rightarrow S^R$ delay had the largest effect. In the FI travel conditions when the $\Delta S \rightarrow S^R$ delay was short (open circles), changeover rates were sometimes higher than in COD conditions (filled circles) with similar $A \rightarrow S^R$ delays. Even so, changeover rates decreased across conditions as the $A \rightarrow S^R$ delay increased and the $\Delta S \rightarrow S^R$ delay remained approximately constant.

As with Experiments 1 and 2, a multiple regression with two independent variables

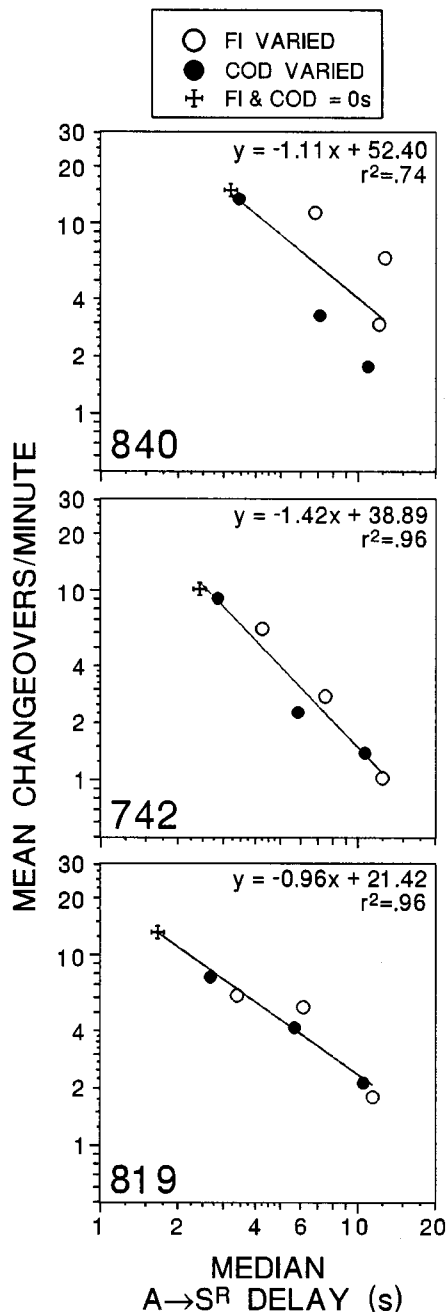


Fig. 7. The relation between mean changeover rates and the median obtained delay between a response on one schedule and a reinforcer on the other (i.e., A→S^R delay). The data are from Experiment 3 and are presented as in Figure 5.

(A→S^R delay duration and COD vs. FI varied) was performed to further examine the contributions of the A→S^R and ΔS→S^R delays. The COD versus FI conditions were entered as a categorical variable, and the FI 0-s COD 0-s condition was excluded. Changeover rates and A→S^R delays were transformed to logarithms prior to the multiple regression. Table 5 shows the outcome of the multiple regression analyses. The overall regression coefficient was significant for each pigeon. Standardized regression coefficients for A→S^R delay duration and COD versus FI revealed that A→S^R delay duration contributed significantly to the prediction of changeover rates for every pigeon, but COD versus FI was non-significant for Pigeons 742 and 819 and only marginally significant for Pigeon 840.

Figure 8 shows main-key response rates in successive 1-s intervals (bins) for the first 15 s after a changeover (i.e., after the main-key stimulus change). The total number of responses in each bin was divided by the total amount of time spent in that bin. The amount of time spent in a bin was obtained by multiplying the bin size (1 s) by the number of times the bin was entered, excluding reinforcement time (cf. Menlove, 1975). In the FI travel conditions, response rates tended to be higher in the first 1 to 2 s following a changeover and did not vary systematically with increases in the duration of the FI. In the COD conditions, response rates were higher in bins nearer the termination of the programmed COD. Differences in response rates for the COD and FI travel requirement were greatest for the 4-s conditions as a result of generally lower response rates across bins for the 8-s COD and quickly declining response rates after the 1-s COD had lapsed.

DISCUSSION

As in Experiments 1 and 2, changeover rates decreased as a negative power function of the A→S^R delay. As the A→S^R delay produced by both FI travel requirements and CODs increased, changeover rates decreased. The A→S^R delay decreased changeover rates even though the ΔS→S^R delay was short and approximately constant across FI conditions. Except for Pigeon 840, similar decreases in changeover rate were obtained when A→S^R delays were associated with changes in the ΔS→S^R delay, as arranged by the COD con-

Table 5

Multiple regression analyses of changeover rates as a function of A→S^R delay duration and COD versus FI for Experiment 3.

Subject	r^2	SE	F	p	Coefficients					
					A→S ^R delay			COD vs. FI		
					β	t	p	β	t	p
840	.87	.16	10.12	.046	-1.05	-4.35	.022	.76	-3.17	.051
742	.97	.09	45.20	.006	-1.01	-9.45	.003	.16	-1.51	.227
819	.91	.09	15.76	.026	-0.96	-5.61	.011	.77	0.45	.682

Note. For all F tests $F(2, 3)$. For all t tests $t(3)$. $\alpha = .05$ for all statistical tests.

ditions. These results are consistent with those from Experiments 1 and 2 and support the notion that the A→S^R delay is primary in determining changeover rates.

In Experiments 1 and 2 the changes in the $\Delta S \rightarrow S^R$ delay also sometimes had a small effect on changeover rates. This effect, however, was reliable only for Pigeon 840 in the present experiment. The conditions in which different $\Delta S \rightarrow S^R$ delays produced differences in changeover rates were often accompanied by biases for one schedule or the other, and

these biases could contribute to the effect. In addition, for Pigeon 840, the proportion of postchangeover reinforcers was higher for FI than for COD conditions, which also may have contributed to the larger differences in changeover rates for this pigeon.

Although the $\Delta S \rightarrow S^R$ delay appears to have little independent role in determining changeover rates, longer $\Delta S \rightarrow S^R$ delays produced longer periods of high-rate responding following a changeover. The $\Delta S \rightarrow S^R$ delay remained relatively constant across the FI travel

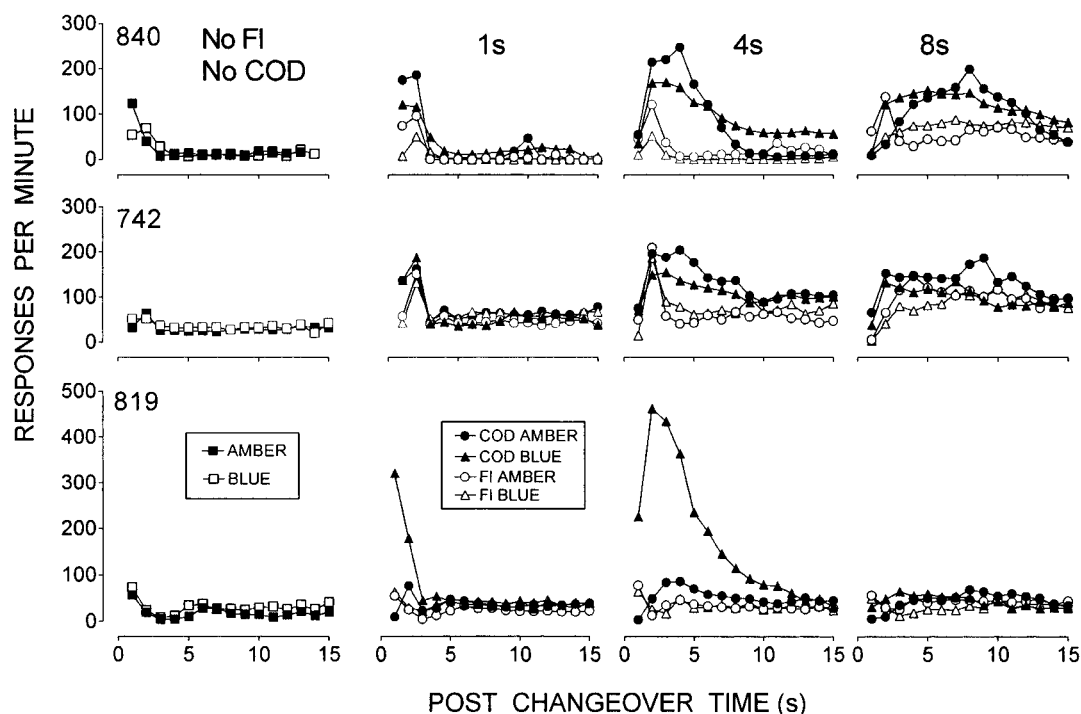


Fig. 8. Local response rates following a changeover for amber and blue schedules in each condition of Experiment 3. Data are from the last 5 days of each condition. Note that the legend is different for the three panels on the left, which represent the condition in which no FI travel requirement or COD was in effect.

requirements, and response rates were elevated near the end of this delay across FI travel durations. The $\Delta S \rightarrow S^R$ delay increased with increases in COD, and periods of high-rate responding tracked the increases in this delay but were less pronounced when the COD was 8 s. Pliskoff (1971) also noted that high rates of responding during the COD were less pronounced at longer durations. These results suggest that the delay to reinforcement after a changeover-produced stimulus change can determine local response patterns.

GENERAL DISCUSSION

Changeover rates decreased with increases in the delay between a response on one schedule and a reinforcer on the other (i.e., the $A \rightarrow S^R$ delay). The delay between a changeover-produced change in stimulus conditions and a reinforcer (i.e., the $\Delta S \rightarrow S^R$ delay) had only small and unreliable effects on changeover rates. However, periods of high-rate responding following a changeover tracked the duration of the $\Delta S \rightarrow S^R$ delay. In what follows, we discuss the $A \rightarrow S^R$ and $\Delta S \rightarrow S^R$ delays separately and then examine the relevance of these delays to understanding concurrent-schedule performance.

The $A \rightarrow S^R$ Delay

Figures 5 and 7 show that changeover rates varied as a negative power function of the $A \rightarrow S^R$ delay, and this relation is consistent with previous descriptions of both the effects of COD duration and travel requirements (e.g., Aparicio & Baum, 1997; Stubbs et al., 1977; Temple et al., 1995). In Experiments 2 and 3, changes in the $A \rightarrow S^R$ delay were produced by manipulating the $\Delta S \rightarrow S^R$ delay or by holding the $\Delta S \rightarrow S^R$ delay constant. Changeover rates decreased with increases in the $A \rightarrow S^R$ delay independently of the confounding effect between the $\Delta S \rightarrow S^R$ and $A \rightarrow S^R$ delays. These findings suggest that the decreased changeover rates produced by longer COD durations (e.g., Bourland & Miller, 1978; Pliskoff, 1971; Shahan & Lattal, 1998; Shull & Pliskoff, 1967; Temple et al., 1995) and travel requirements (e.g., Aparicio & Baum, 1997; Baum, 1982; Davison, 1991; McCarthy et al., 1994) are due primarily to changes in the $A \rightarrow S^R$ delay. Thus, the present experiments support previous assumptions

about the functional equivalence of travel requirements and CODs on changing over (e.g., Baum, 1982; Davison, 1991) and suggest that the $A \rightarrow S^R$ delay is primarily responsible for the effects of both procedures on changing over.

The $\Delta S \rightarrow S^R$ Delay

At similar $A \rightarrow S^R$ delays, changeover rates sometimes were marginally higher when the $\Delta S \rightarrow S^R$ delay was short than when it was long (Figures 3, 5, and 7). In the present experiments, a peck that completed an FI travel requirement darkened the changeover key and changed the main-key stimulus, thereby introducing a signaled delay from this stimulus change to a probabilistically arranged reinforcer. This delay value was manipulated in some conditions by varying the COD duration. Findley (1958) suggested that changing over is maintained in part by the conditioned reinforcement provided by such main-key stimulus changes (cf. Kelleher & Gollub, 1962, pp. 573–575). Longer $\Delta S \rightarrow S^R$ delays would be expected to diminish the conditioned reinforcing properties of the main-key stimulus change (cf. Fantino, 1969, 1977). The sometimes-higher changeover rates produced by short $\Delta S \rightarrow S^R$ delays may reflect such differences in the conditioned reinforcing effects of the main-key stimulus change; however, any such conditioned reinforcement effect was small relative to the effect of the $A \rightarrow S^R$ delay.

In some respects it is surprising that the effects of the $\Delta S \rightarrow S^R$ delay were not larger and more consistent. The $\Delta S \rightarrow S^R$ delay was varied in the present experiments by changing the duration of the COD, and thus the minimum stay duration required for a reinforcer to be delivered. Nonetheless, changeover rates varied considerably with the $A \rightarrow S^R$ delay regardless of whether the $\Delta S \rightarrow S^R$ delay required longer stay durations (i.e., COD manipulated) or not (i.e., travel requirement manipulated). This finding supports the notion that changing over is determined not only by the duration of a stay required for reinforcement but also by the duration of the delay from leaving an alternative to the delivery of a reinforcer on the other alternative. Such independent effects of delays for staying versus delays for switching have been dem-

onstrated previously with asymmetrical CODs (Pliskoff, 1971).

In the conditions of the present experiments, the $A \rightarrow S^R$ delay decreased changeover rates regardless of the stimuli correlated with arriving at the changed-to schedule. A different outcome could result when the reinforcement rates correlated with the two schedules are different. The different probabilities of reinforcement for staying versus switching (see MacDonall, 1998, 1999) arranged by different relative reinforcement rates could interact with the effects of changes in the $\Delta S \rightarrow S^R$ delay, the $A \rightarrow S^R$ delay, or both.

Despite its small and inconsistent effects on changing over, the $\Delta S \rightarrow S^R$ delay affected local response patterns following a changeover. In Experiment 3, CODs arranged longer $\Delta S \rightarrow S^R$ delays, and local response rates were higher near the end of these delays. Similarly, local response rates were elevated near the end of the short and relatively constant $\Delta S \rightarrow S^R$ delays obtained with FI travel requirements. Elevated response rates during the COD have been reported previously (e.g., Pliskoff, 1971; Pliskoff et al., 1978; Shahan & Lattal, 1998; Silberberg & Fantino, 1970). In addition, Pliskoff et al. found that response rates were elevated only briefly (1 to 2 s) after a changeover when an FR 5 changeover requirement was in effect. Experiment 3 (Figure 8) extends these findings by showing brief elevations of response rates across a range of FI travel requirements. In addition, the results of Experiment 3 suggest that the pattern of responding during the COD varies with the duration of the COD and that elevated postchangeover response rates for both travel requirements and CODs are likely a function of the $\Delta S \rightarrow S^R$ delay.

$A \rightarrow S^R$ and $\Delta S \rightarrow S^R$ Delays and Concurrent-Schedule Performance

Across a wide range of durations, CODs usually reduce undermatching, but typically fail to eliminate it (e.g., Baum, 1979; Temple et al., 1995). Baum (1982) suggested that responses during the COD could be discarded from matching calculations because the COD is a discriminated period of time, much like a travel requirement, that is separable from responding at the available alternatives. As evidence for the argument that the COD is discriminated, Baum noted that responding dur-

ing the COD occurs at a higher rate than responding after the COD. Removing COD responding generally results in overmatching and brings choice relations obtained with CODs into agreement with those obtained with travel requirements (Baum, 1974; Silberberg & Fantino, 1970; but see Shahan & Lattal, 1998). Similarly, Temple et al. (1995) noted that a model suggested by Davison (1991) more accurately accounted for the effects of changes in COD duration on matching when COD responding was removed.

Ignoring responding during the COD may bring consistency to theoretical accounts of choice, but it does not render inconsequential the molecular aspects of concurrent-schedule performance (cf. Dreyfus et al., 1993). The pattern of responding upon arriving at an alternative appears to be determined in part by the delay from arriving at the alternative to a reinforcer delivery. In Experiment 3, both CODs and travel requirements produced periods of high-rate responding near the end of the $\Delta S \rightarrow S^R$ delay. One question that arises from this finding is whether elevated response rates during the $\Delta S \rightarrow S^R$ delay produced with travel requirements also should be discarded from matching calculations for the sake of consistency. In addition, should the high rates of postchangeover responding when no COD or travel requirement is in effect (Figure 8, left panels) also be discarded? In all these cases, responding during the $\Delta S \rightarrow S^R$ delay occurs at a higher rate than after the $\Delta S \rightarrow S^R$ delay and thus arguably is discriminated from responding at the alternatives (cf. Baum, 1982). As a result, is this responding then separable from responding at the alternatives? In our view, the $\Delta S \rightarrow S^R$ delay and the high rates of responding it produces are natural outcomes of concurrently available alternatives rather than unfortunate inconveniences to be discarded. Leaving one alternative for another necessarily involves a change in stimulus conditions, and the delay between this change in stimulus conditions and a reinforcer may be an important determinant of local patterns of responding *to the alternatives* (not of responding that is somehow separate from the alternatives). Understanding the determinants of these local patterns of responding to the alternatives is important because, as noted

above, they can have a large impact on our characterizations of choice.

The effects of the $A \rightarrow S^R$ delay have been interpreted in the present experiments as being the result of delaying reinforcement for changing over. The suggestion that increases in COD or travel durations have their effects by increasing the time taken to change over is not controversial (e.g., Davison, 1991; McCarthy et al., 1994); however, the mechanisms by which this time has its effects are unclear. Davison's (1991) model assumes that the time taken to change over punishes changing over by specifying periods of nonreinforcement (see also Davison & Elliffe, 2000). Such a view stands in contrast to that of the present experiments and others (e.g., Pliskoff, 1971; Shull et al., 1981) in which the time taken to change over is assumed to have its effects by delaying reinforcement for changing over. Differentiating these two views could be difficult. For example, the relations between changeover rates and the $A \rightarrow S^R$ delay shown in Figures 5 and 7 in the present experiments were reanalyzed in terms of median time spent changing over (based on every changeover), rather than median time spent changing over only for those changeovers followed by a reinforcer (i.e., the $A \rightarrow S^R$ delay). These two functions, one based on the average period of nonreinforcement incurred by changing over and the other based on obtained delays to reinforcement following a changeover, were indistinguishable.

Although the present experiments were not designed to differentiate reinforcement-delay and punishment-based accounts of the effects of CODs and travel requirements, other data suggest that a delay-based account may be most appropriate. For example, Shull et al. (1981) found that changing over was maintained with a short delay to reinforcement even though changing over dramatically decreased overall reinforcement rate. The results of Shull et al. and other experiments (e.g., Rachlin & Green, 1972; Thomas, 1981) suggest that behavior is particularly sensitive to reinforcement delay and is particularly insensitive to reinforcement loss. Nonetheless, further differentiation between reinforcement-delay and punishment-based accounts of changing over awaits additional research.

REFERENCES

- Aparicio, C. F., & Baum, W. M. (1997). Comparing locomotion with lever-press travel in an operant simulation of foraging. *Journal of the Experimental Analysis of Behavior*, 68, 177-192.
- Baum, W. M. (1974). On two types of deviation from the matching law: Bias and undermatching. *Journal of the Experimental Analysis of Behavior*, 22, 231-242.
- Baum, W. M. (1979). Matching, undermatching, and overmatching in studies of choice. *Journal of the Experimental Analysis of Behavior*, 32, 269-281.
- Baum, W. M. (1982). Choice, changeover, and travel. *Journal of the Experimental Analysis of Behavior*, 38, 35-49.
- Baum, W. M., & Aparicio, C. F. (1999). Optimality and concurrent variable-interval variable-ratio schedules. *Journal of the Experimental Analysis of Behavior*, 71, 75-89.
- Baum, W. M., Schwendiman, J. W., & Bell, K. E. (1999). Choice, contingency discrimination, and foraging theory. *Journal of the Experimental Analysis of Behavior*, 71, 355-373.
- Bourland, G., & Miller, J. T. (1978). Role of discriminative stimuli in concurrent performances: Duration of changeover delay. *The Psychological Record*, 28, 263-271.
- Catania, A. C. (1963). Concurrent performances: Reinforcement interaction and response independence. *Journal of the Experimental Analysis of Behavior*, 6, 253-263.
- Catania, A. C. (1966). Concurrent operants. In W. K. Honig (Ed.), *Operant behavior: Areas of research and application* (pp. 213-270). Englewood Cliffs, NJ: Prentice Hall.
- Catania, A. C., & Cutts, D. (1963). Experimental control of superstitious responding in humans. *Journal of the Experimental Analysis of Behavior*, 6, 203-208.
- Davison, M. (1991). Choice, changeover and travel: A quantitative model. *Journal of the Experimental Analysis of Behavior*, 55, 47-61.
- Davison, M., & Elliffe, D. (2000). Travel time and concurrent-schedule choice: Retrospective versus prospective control. *Journal of the Experimental Analysis of Behavior*, 73, 65-77.
- Davison, M., & McCarthy, D. (1988). *The matching law: A research review*. Hillsdale, NJ: Erlbaum.
- Davison, M., & McCarthy, D. (1994). Leaving patches: An investigation of a laboratory analogue. *Journal of the Experimental Analysis of Behavior*, 62, 89-108.
- deVilliers, P. A. (1977). Choice in concurrent schedules and a quantitative formulation of the law of effect. In W. K. Honig & J. E. R. Staddon (Eds.), *Handbook of operant behavior* (pp. 233-287). New York: Prentice Hall.
- Dreyfus, L. R., DePorto-Callan, D., & Pesillo, S. A. (1993). Changeover contingencies and choice on concurrent schedules. *Animal Learning & Behavior*, 21, 203-213.
- Fantino, E. (1969). Choice and rate of reinforcement. *Journal of the Experimental Analysis of Behavior*, 12, 723-730.
- Fantino, E. (1977). Conditioned reinforcement: Choice and information. In W. K. Honig & J. E. R. Staddon (Eds.), *Handbook of operant behavior* (pp. 313-339). New York: Prentice Hall.

- Findley, J. D. (1958). Preference and switching under concurrent scheduling. *Journal of the Experimental Analysis of Behavior*, 1, 123-144.
- Fleshler, M., & Hoffman, H. S. (1962). A progression for generating variable-interval schedules. *Journal of the Experimental Analysis of Behavior*, 5, 529-530.
- Herrnstein, R. J. (1961). Relative and absolute strength of response as a function of frequency of reinforcement. *Journal of the Experimental Analysis of Behavior*, 4, 267-272.
- Herrnstein, R. J. (1982). Melioration as behavioral dynamism. In M. L. Commons, R. J. Herrnstein, & H. Rachlin (Eds.), *Quantitative analyses of behavior: Vol. 2. Matching and maximizing accounts* (pp. 433-458). Cambridge, MA: Ballinger.
- Herrnstein, R. J. (1991). Experiments on stable suboptimality in individual behavior. *American Economic Review*, 81, 360-364.
- Herrnstein, R. J., & Vaughan, W. (1980). Melioration and behavioral allocation. In J. E. R. Staddon (Ed.), *Limits to action: The allocation of individual behavior* (pp. 143-176). New York: Academic Press.
- Heyman, G. M. (1979). A Markov model description of changeover probabilities on concurrent variable-interval schedules. *Journal of the Experimental Analysis of Behavior*, 31, 41-51.
- Jones, B. M., & Davison, M. (1996). Residence time and choice in concurrent foraging schedules. *Journal of the Experimental Analysis of Behavior*, 65, 423-444.
- Kelleher, R. T., & Gollub, L. R. (1962). A review of positive conditioned reinforcement. *Journal of the Experimental Analysis of Behavior*, 5, 543-597.
- MacDonall, J. S. (1998). Run length, visit duration, and reinforcers per visit in concurrent performance. *Journal of the Experimental Analysis of Behavior*, 69, 275-293.
- MacDonall, J. S. (1999). A local model of concurrent performance. *Journal of the Experimental Analysis of Behavior*, 71, 57-74.
- Mazur, J. E. (1991). Choice. In I. H. Iversen & K. A. Lattal (Eds.), *Experimental analysis of behavior* (Part 1, pp. 219-249). Amsterdam: Elsevier Science Publishers BV.
- McCarthy, D., Voss, P., & Davison, M. (1994). Leaving patches: Effects of travel requirements. *Journal of the Experimental Analysis of Behavior*, 62, 185-200.
- Menlove, R. L. (1975). Local patterns of responding maintained by concurrent and multiple schedules. *Journal of the Experimental Analysis of Behavior*, 23, 309-337.
- Myerson, J., & Miezin, F. M. (1980). The kinetics of choice: An operant systems analysis. *Psychological Review*, 87, 160-174.
- Pliskoff, S. S. (1971). Effects of symmetrical and asymmetrical changeover delays on concurrent performances. *Journal of the Experimental Analysis of Behavior*, 16, 249-256.
- Pliskoff, S. S., Cicerone, R., & Nelson, T. D. (1978). Local response rate constancy on concurrent variable-interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, 29, 431-446.
- Rachlin, H., & Green, L. (1972). Commitment, choice and self-control. *Journal of the Experimental Analysis of Behavior*, 17, 15-22.
- Shahan, T. A., & Lattal, K. A. (1998). On the functions of the changeover delay. *Journal of the Experimental Analysis of Behavior*, 69, 141-160.
- Shimp, C. P. (1966). Probabilistically reinforced choice behavior in pigeons. *Journal of the Experimental Analysis of Behavior*, 9, 443-455.
- Shimp, C. P. (1969). Optimal behavior in free-operant experiments. *Psychological Review*, 76, 97-112.
- Shull, R. L., & Pliskoff, S. S. (1967). Changeover delay and concurrent schedules: Some effects on relative performance measures. *Journal of the Experimental Analysis of Behavior*, 10, 517-527.
- Shull, R. L., Spear, D. J., & Bryson, A. E. (1981). Delay or rate of food delivery as a determiner of response rate. *Journal of the Experimental Analysis of Behavior*, 35, 129-143.
- Silberberg, A., & Fantino, E. (1970). Choice, rate of reinforcement, and the changeover delay. *Journal of the Experimental Analysis of Behavior*, 13, 187-197.
- Silberberg, A., Hamilton, B., Zirix, J. M., & Casey, J. (1978). The structure of choice. *Journal of Experimental Psychology: Animal Behavior Processes*, 4, 368-398.
- Skinner, B. F. (1950). Are theories of learning necessary? *Psychological Review*, 57, 193-216.
- Stubbs, D. A., Pliskoff, S. S., & Reid, H. M. (1977). Concurrent schedules: A quantitative relation between changeover behavior and its consequences. *Journal of the Experimental Analysis of Behavior*, 25, 85-96.
- Temple, W., Scown, J. M., & Foster, T. M. (1995). Changeover delay and concurrent-schedule performance in domestic hens. *Journal of the Experimental Analysis of Behavior*, 63, 71-95.
- Thomas, G. (1981). Contiguity, reinforcement rate and the law of effect. *Quarterly Journal of Experimental Psychology*, 33B, 33-43.
- Vaughan, W., Jr. (1981). Melioration, matching, and maximization. *Journal of the Experimental Analysis of Behavior*, 36, 141-149.
- Vaughan, W., Jr. (1982). Choice and the Rescorla-Wagner model. In M. L. Commons, R. J. Herrnstein, & H. Rachlin (Eds.), *Quantitative analyses of behavior: Vol. 2. Matching and maximizing accounts* (pp. 263-279). Cambridge, MA: Ballinger.
- Williams, B. A. (1988). Reinforcement, choice, and response strength. In R. C. Atkinson, R. J. Herrnstein, G. Lindzey, & R. D. Luce (Eds.), *Stevens' handbook of experimental psychology* (2nd ed., pp. 167-244). New York: Wiley.
- Williams, B. A., & Bell, M. C. (1996). Changeover behavior and preference in concurrent schedules. *Journal of the Experimental Analysis of Behavior*, 65, 513-526.
- Williams, B. A., & Bell, M. C. (1999). Preference after training with differential changeover delays. *Journal of the Experimental Analysis of Behavior*, 71, 45-55.

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